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MASSACHUSETTS COASTAL COMMERCIAL LOBSTER TRAP SAMPLING PROGRAM MAY-NOVEMBER, 1998

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and
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COMMONWEALTH OF MASSACHUSETTS
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David M. Peters, Commissioner

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December 6, 1999

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ABSTRACT

This is the Massachusetts Division of Marine Fisheries eighteenth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. During the period of May through November, 1998, seventy-eight (78) sampling trips were made aboard commercial lobster vessels. A total of 35,568 lobster was sampled from 15,858 trap hauls. The catch rate of marketable lobster, 0.662 lobster per trap, was 15% lower than the 1997 index, 0.776. The proportion of females ovigerous, 16.4%, was higher than in the previous year (14.7%). The coastwide fishing mortality estimate, 1.36, was similar to the 1997 index of 1.33. Exploitation rate, 0.67, mean carapace length of marketable lobster, 88.9mm, and mean size of egg-bearing females, 86.4 mm, dropped only fractionally. The cull rate, 20.9%, was similar to the 1997 estimate of 20.4%. Less than 1% of the lobster sampled from traps were dead.

An index of pre-recruit abundance was created using data from our sea sampling database. The catch rate of lobster in the pre-recruit size class provided the basis of the index. The index was calculated from a multiple regression of log transformed catch rates with the following factors: month, year, lobsterman. The back-transformed regression coefficient associated with the factor "year", adjusted for the effects of the other analyzed factors, provided the index of pre-recruit abundance. The relationship between the index and Massachusetts territorial waters catch in the following year was modelled using a power function. The resulting equation was used to calculate predicted landings which differed from the actual landings for the years 1981-1998 by 0.34 to 27.6% with a mean difference of 7.27%.

A time series of data from our bottom water temperature monitoring program is presented for seven locations in Buzzards Bay, Cape Cod, and Massachusetts Bay.

INTRODUCTION

This is the Massachusetts Division of Marine Fisheries (DMF) eighteenth annual assessment of the status of the American lobster resource in Massachusetts coastal waters. Since the lobster resource supports the most economically important single-species fishery in Massachusetts coastal waters, a long-term coastwide lobster monitoring program yielding biological and catch per unit effort data was devised and initiated in Massachusetts in May, 1981. A sea sampling/survey design was chosen by which both catch per unit effort and biological data could be collected temporally and areally with sufficient precision for stock assessments. The objective was to assess variations in population parameters due to environmental factors, fishing pressure, and regulatory changes.

Data collected during the 1998 coastwide commercial lobster trap sampling program are summarized below. Parameter trends occurring during the 1981-1998 study period are presented.

STUDY AREA

The study area is primarily defined by the Massachusetts territorial sea, except where lobstering activities of cooperating commercial lobstermen exceeded territorial boundaries (Figure 1). Territorial waters total 5,322 sq km (2,055 sq n mi), of which an estimated 60% is considered major lobster habitat. Six sampling regions, Cape Ann, Beverly-Salem, Boston Harbor, Cape Cod Bay, outer Cape Cod, and Buzzards Bay, were chosen for coverage of the major lobstering regions of the state. For convenience, these regions are depicted in Figure 1 as generalized hatch-marked areas wherein lobster gear sampled may be discontinuously distributed.

SAMPLING PROCEDURE

Sampling of coastal waters was accomplished by monitoring catches during the normal lobstering operations of volunteer commercial lobstermen in each designated region. Multiple lobstering operations were observed to reduce bias from varying degrees of lobstering skill and to enhance areal coverage. Pot-sampling trips were day trips, conducted a minimum of once per month per region during the major lobstering season, May-November.

Utilizing portable cassette tape recorders, sea samplers recorded carapace length (to the nearest mm); sex; and condition, including the degree of shell hardness, culls and other shell damage, external gross pathology, mortality, and presence of extruded ova on females (ovigerous). Catch in number of lobster, number of trap hauls, set-over-days, trap and bait type were also recorded. Trap locations were recorded from LORAN and plotted on nautical charts. Depth information was then acquired from the charts as a coastwide standard to avoid variability from tidal fluctuations.

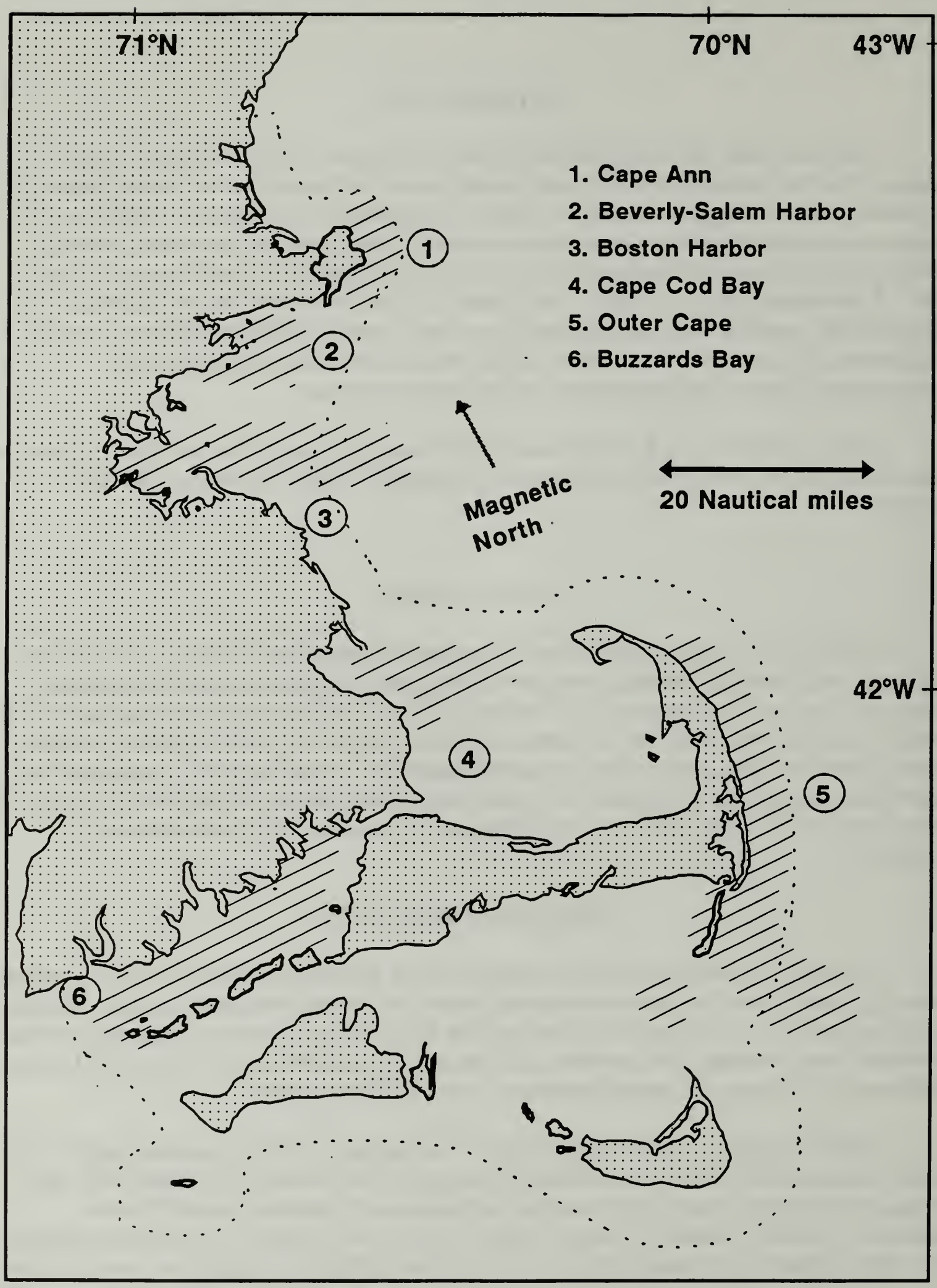

Figure 1. Map of Massachusetts with six sampling regions (hatch-marked) and territorial sea boundary (dotted line) indicated.

ANALYTICAL PROCEDURES

Data were computer coded and keypunched with a microcomputer data entry program. The data base was subsequently transferred for analysis to the Massachusetts Executive Office of Environmental Affairs' (EOEA) Digital Equipment Corporation VAX-11/780 computer system. A computer auditing process was used to uncover keypunch and recording errors and statistical analyses were performed with SPSS (Nie 1983) statistical sub-programs.

Because parameter means exhibit significant regional and monthly variation, an areal and temporal data weighting scheme was incorporated into analytical software. As a result, each month's data contribute equally to regional parameter means which are weighted by area in square nautical miles to generate coastwide means.

Unless specified otherwise, the terms "legal" or "legal sized" lobster include all lobster in the carapace length category $\geq$ 82.6 mm. The marketable segment of this category, which excludes ovigerous females, is analyzed separately and referred to as "marketable lobster". The sublegal length category includes all lobster < 82.6 mm.

The catch rates of marketable lobster are expressed as CTH'_3. This is catch per trap haul standardized to 3 set-over-days (Estrella and McKiernan 1989).

Estimates of total instantaneous mortality (Z) and total annual mortality ($A=1-e^{-Z}$) were computed by two methods which produce extremes in the possible range of estimates. The method of Gulland (1969) requires computation of the regression line slope of natural log-transformed numbers at estimated age (15% molt groups, 14% for Buzzards Bay, were derived from tagging data). Beverton and Holt's (1956) process employs von Bertalanffy Growth Equation parameters (from Fair 1977) and mean and minimum length of exploitable sizes.

Estimates of fishing mortality (F) were calculated with cohort analysis (Pope 1972, Jones 1974). Rates of exploitation were calculated with the equation $u=FA/Z$, where F= fishing mortality, A= total annual mortality, and Z= total instantaneous mortality.

Lobster landings data were derived from lobstermen's catch reports which are compiled annually by the DMF Commercial Fisheries Statistics Project.

Since current management strategy stresses uniform coastwide regulations, all data are grouped for a coastwide analysis. However, the uniqueness of the Massachusetts coastline, its role as a temperature barrier which profoundly affects many marine species (Colton 1964), and the influence of offshore lobster stocks on the inshore resource mandate a regional data treatment as well.

RESULTS AND DISCUSSION

Commercial Lobster Sampling

During the period of May through November, 1998, seventy-eight (78) sampling trips were made aboard commercial lobster vessels in Massachusetts coastal waters. A total of 35,568 lobster was sampled from 15,858 trap hauls.

The 1998 coastwide mean catch per unit effort index (CTH'_3), 0.662marketable lobster per trap, was 15% lower than the 1997 index, 0.776 (Appendix Table 1). Total Massachusetts commercial landings, 13,236,091 lbs, decreased by 12% from 1997. Landings from territorial waters, 7,660,274 lbs, decreased by 9%. Landings and catch rate trends are depicted in Figure 2. The coastwide mean catch rates of sublegal lobster decreased by only 19% (CTHSOD) and 11% (CTHAUL) from 1997. These represent new time series lows (Appendix Tables 2 and 3).

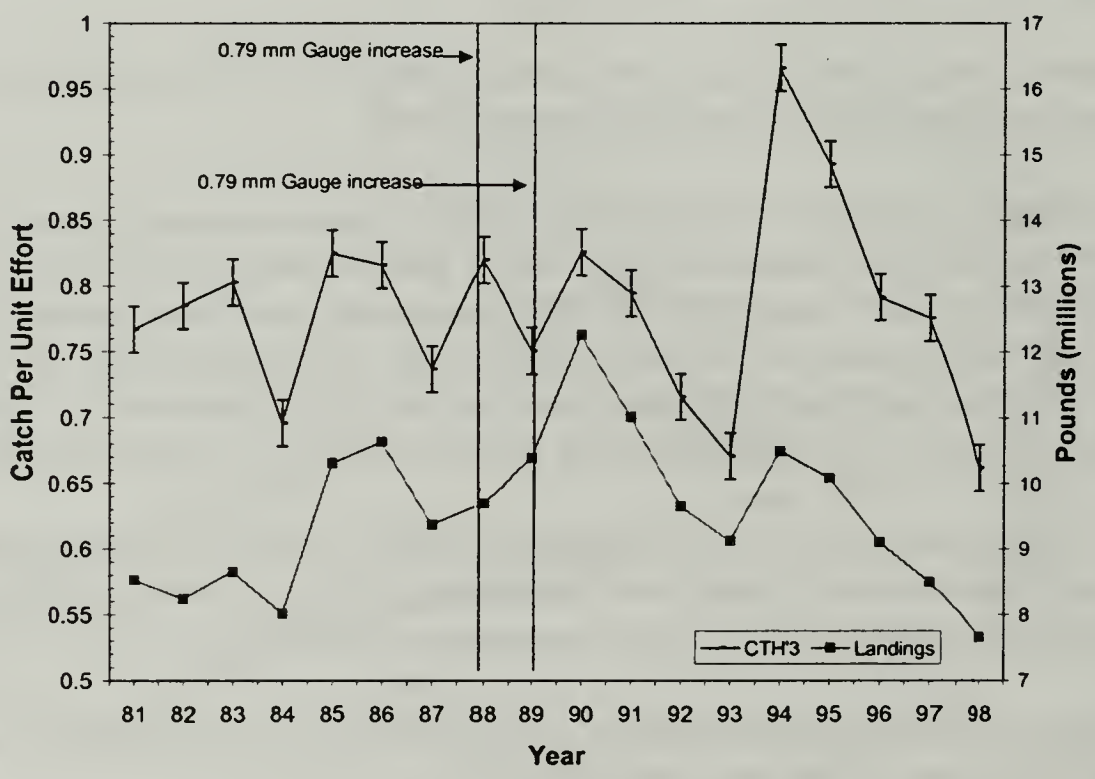

Figure 2. Catch per unit effort of marketable American lobster from commercial trap sampling and Massachusetts lobster landings from territorial water, 1981 - 1998.

Of all females sampled during 1998, 16.4% were ovigerous compared to 14.7% in 1997 (Appendix Table 4). However, trends in CPUE of ovigerous females (Appendix Tables 5-6) declined and are depicted in Figure 3.

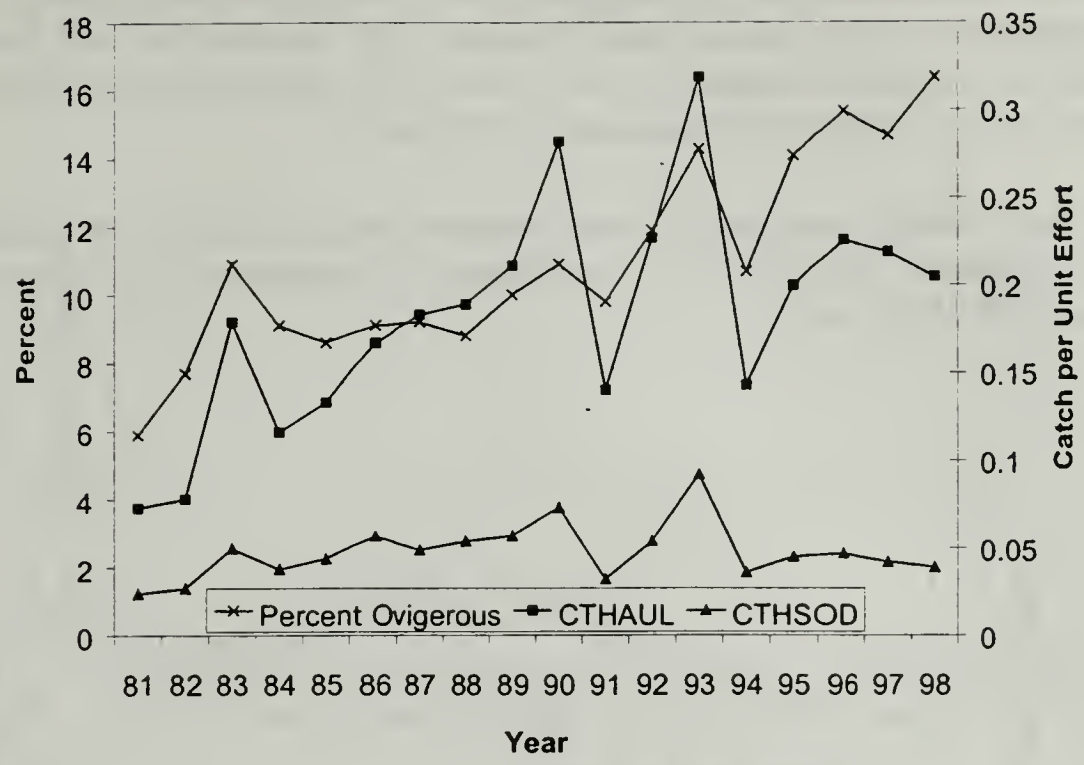

Figure 3. Relative abundance of ovigerous female American lobster in percent total females and catch per effort, Massachusetts coastal waters, 1981 - 1998.

Approximately 92% of the legal catch in our inshore regions (Cape Ann south through Cape Cod Bay and Buzzards Bay) was comprised of new recruits (83 mm-94 mm CL), i.e., lobster which recruited to the legal size range during their most recent molt (Appendix Table 7). This index of the effect of fishing pressure on the size frequency was 4% higher than1997. The index fluctuated from 57% in 1997 to 58% in 1998 for the primarily offshore migrant lobster sampled east of Cape Cod. Estimates of total mortality (Z) for inshore Gulf of Maine regions (Z = 1.52-2.81, A = 78%-94%) and Buzzards Bay (Z = 2.57-3.27, A = 92%-96%) depict a heavily exploited resource while those for the outer Cape Cod region (Z = 0.76-0.86, A = 53%-58%) indicate that a lower level of fishing pressure was exerted on this lobster group (Appendix Tables 8a and 8b).

Estimates of instantaneous fishing mortality (F), the proportion of all deaths which are attributed to fishing, ranged from 0.64 off outer Cape Cod to 2.13 in Buzzards Bay (Appendix Table 9). Exploitation rates (*u*), i.e. the fraction of the population that is removed by fishing, were similar to 1997 data (Appendix Table 10).

The relationship between fishing mortality, rate of exploitation, and mean lobster size is depicted in Figure 4. Carapace length exhibited a downward trend as fishing mortality and exploitation rates increased through 1987. Thereafter, increases in mean carapace length of 0.7 mm occurred in 1988 (mean size = 88.2 mm) and 1989 (mean size = 88.9 mm, Appendix Table 11) which reflected the similar numerical change in the minimum legal size during those years. Carapace length then fluctuated downward until 1994, and achieved a time series high during

1995 – 1997 before declining to a 1990 average in 1998. Fishing mortality rates for all regions combined edged upward to a time-series high of 1.48 in 1993, declined in 1994-1996 along with exploitation rates, then fluctuated upward in 1997-1998. The relative change in size frequency between 1997 and 1998 is depicted by the overlay in Figure 5.

Sublegal sized lobster averaged 77.2 mm carapace length during 1998 compared to 77.8 mm during 1997 (Appendix Table 12). The mean size of all ovigerous females was similar between 1997 and 1998 (86.4 mm).

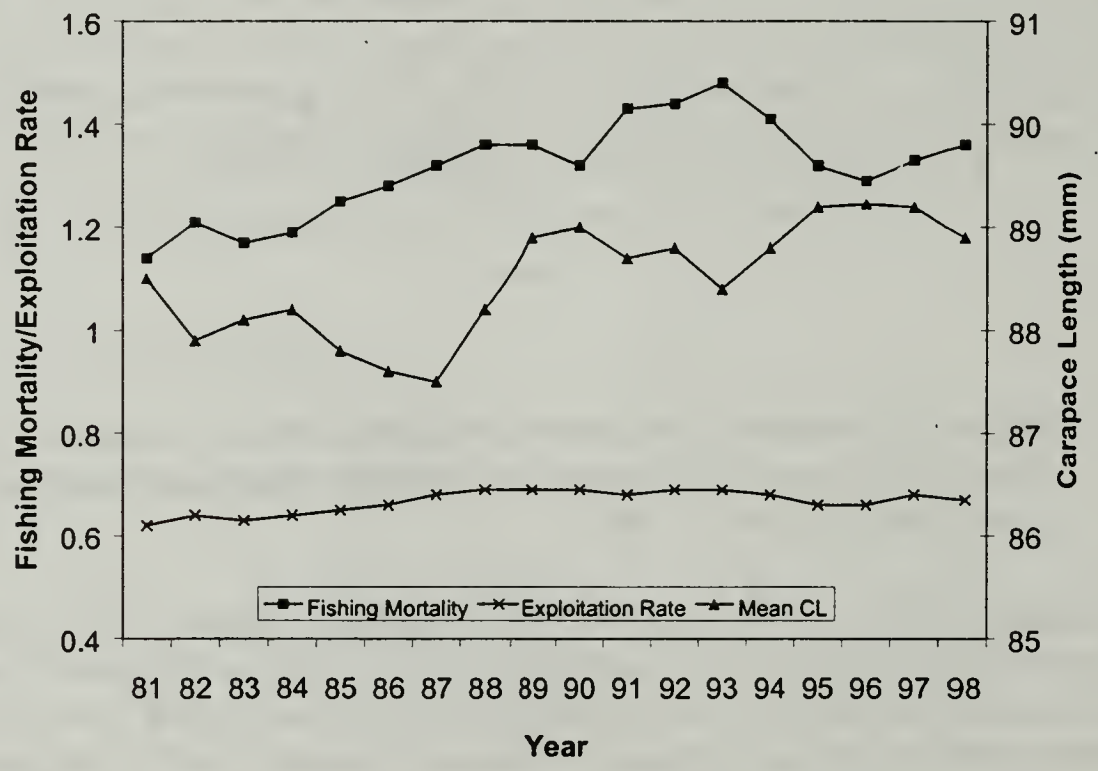

Figure 4. Relationship between exploitation rate, fishing mortality, and mean carapace length of marketable American lobster, Massachusetts coastal water, 1981 - 1998.

The percentage of culls (lobster with one or both claws missing or regenerating) among all lobster sampled was similar between 1997 (20.4%) and 1998 (20.9%) (Appendix Table 14). The cull rates for legal, marketable, and sublegal size groups remained comparable between years, increasing by only a fraction of a percent (Appendix Tables 15-17).

The coastwide incidence of lobster found dead in traps was 0.15%. This was similar to that of the previous year (Appendix Table 18) and is acceptably low.

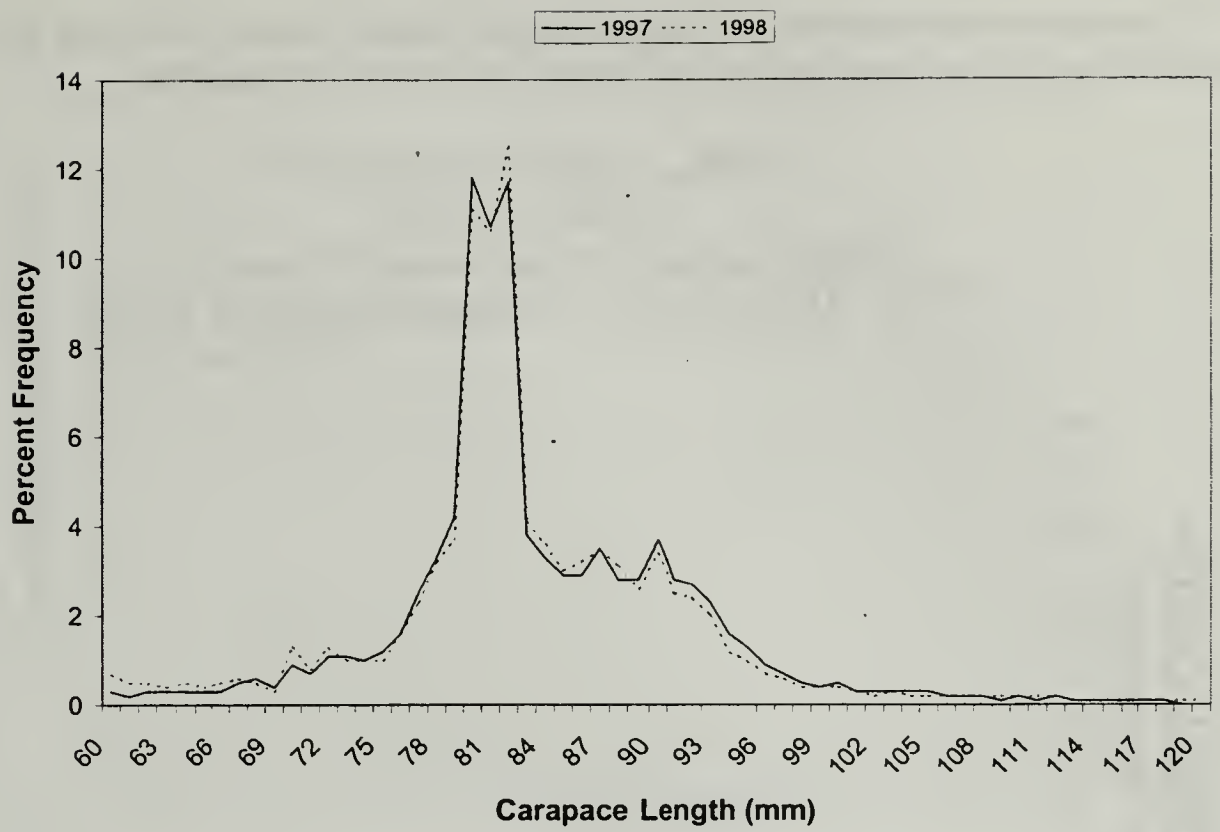

Figure 5. Length frequencies of trap-caught American lobster, Massachusetts coastal waters, 1997 - 1998.

Index of Pre-Recruit Abundance

We created an index of abundance for pre-recruit lobster with data from our sea sampling program. The catch rate (number caught per trap haul) of lobster in the pre-recruit size class provided the basis of the index. The pre-recruit size range changed with increases in minimum legal size (68-80 mm carapace length for the years 1981-1987; 69-81 mm for 1988; and 70-82 mm for 1989 and later). The index was calculated from a multiple regression of logarithmically-transformed catch rates with the following factors: month, year, lobsterman. Other factors including soak time, bait, and trap type were incorporated in the preliminary regressions but failed to improve the fit and so they were excluded from the model. The back-transformed regression coefficients associated with the factor "year", adjusted for the effects of the other analyzed factors, provide the index of pre-recruit abundance (IPA). This approach using regression/ANOVA modelling in the standardization of catch rates has been used successfully to create indices of juvenile abundance in the Western Australia rock lobster (*Panulirus cygnus*) fishery (Caputi and Brown, 1986).

The relationship between the IPA and territorial catch in the following year (Figure 6) was modelled using a power function resulting in the following equation:

$$\mathbf{Catch_{t+1} = 9{,}632{,}949(IPA_t)^{0.7553}}$$

$r^2=0.367$; $p<0.001$

where $\mathbf{Catch_{t+1}}$ = territorial catch in year t+1

$\mathbf{IPA_t}$ = index of pre-recruit abundance in year t

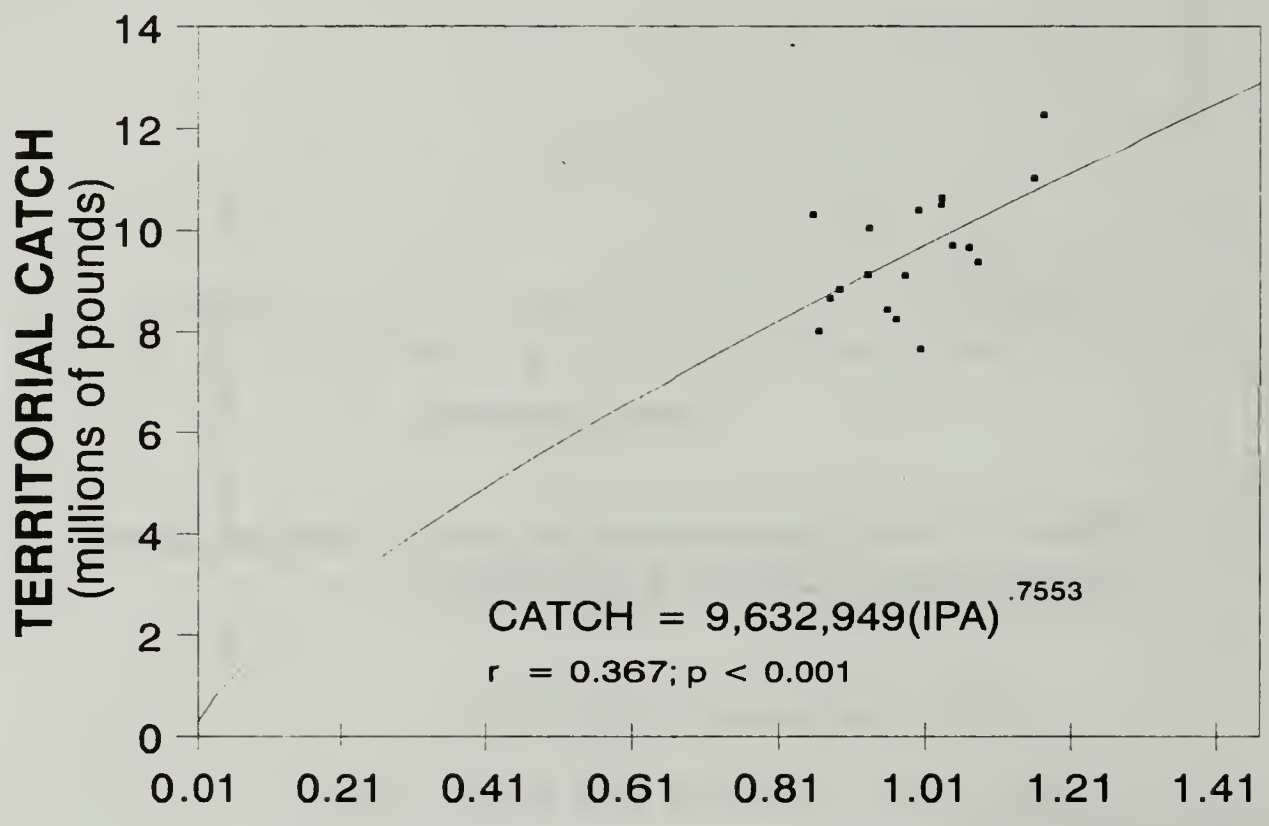

Figure 6. Relationship between the index of pre-recruit abundance and Massachusetts territorial catch one year later.

This equation was used to predict territorial landings. The model predicts an increase in territorial landings for 1999 to 8,838,217 lbs.

The relationship between predicted territorial landings and actual territorial landings is shown in Figure 7. The predicted values differed from the actual values by 0.34 to 27.6% with a mean difference of 7.27%. The relatively tight fit between predicted and actual landings ($r=0.64$, $p=0.005$) indicates the model provides modest predictive power for territorial landings.

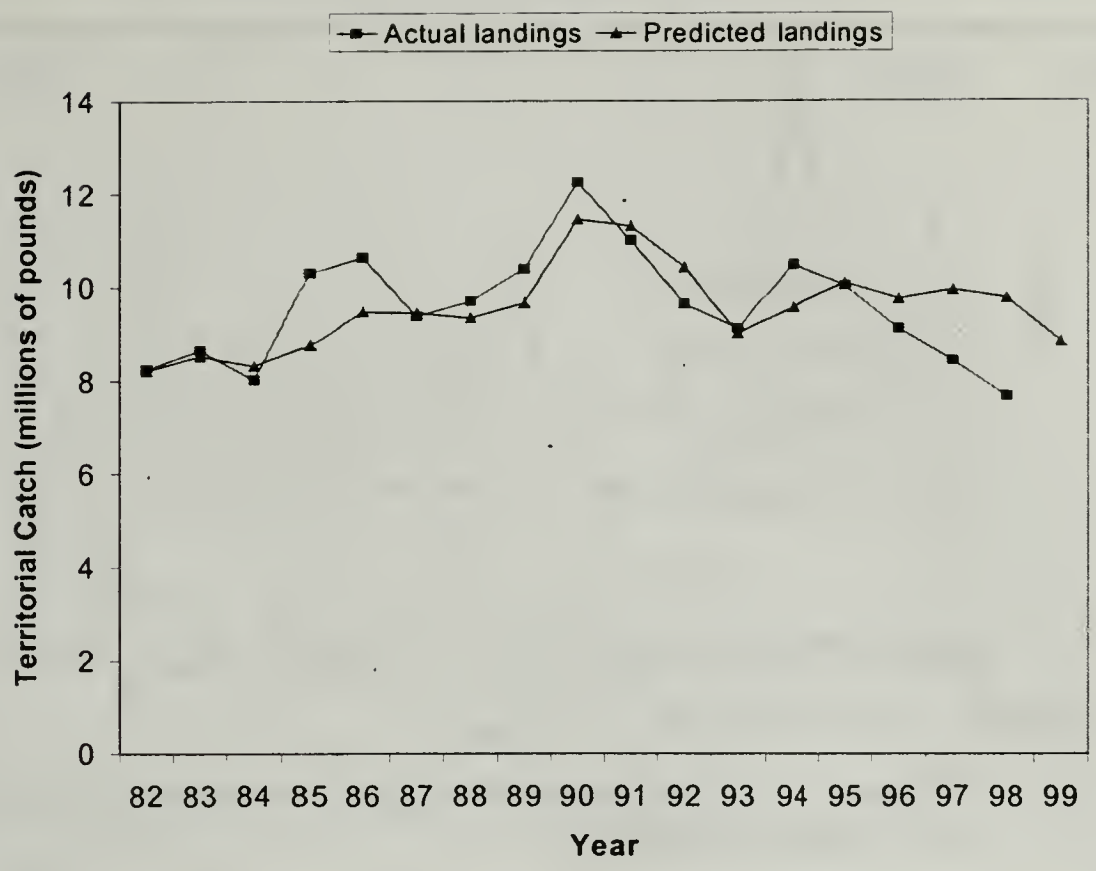

Figure 7. Relationship between predicted landings based on the pre-recruit abundance index and actual territorial landings.

The model's predictive capabilities were evaluated via graphical analysis. The absolute percent change in actual landings from one year to the next was overlaid with the absolute percent change in predicted landings. Percent change of actual landings (3.21% to 28.5 %, mean = 9.9%) varied from year to year and had a higher mean percent change than predicted landings(0.22% to 18.65%, mean = 5.28%) (Figure 8). This indicates that the catch rate of pre-recruit lobsters in the previous year accounts for approximately 50% of the variation in territorial landings over the time series. The remaining variance associated with territorial landings is likely attributed to changes in fishing effort and environmental conditions, especially temperature. As is, the model has limited forecasting value. However, it is likely that its predictive capability would be enhanced if accurate estimates of changes in fishing effort and water temperature were integrated into the model.

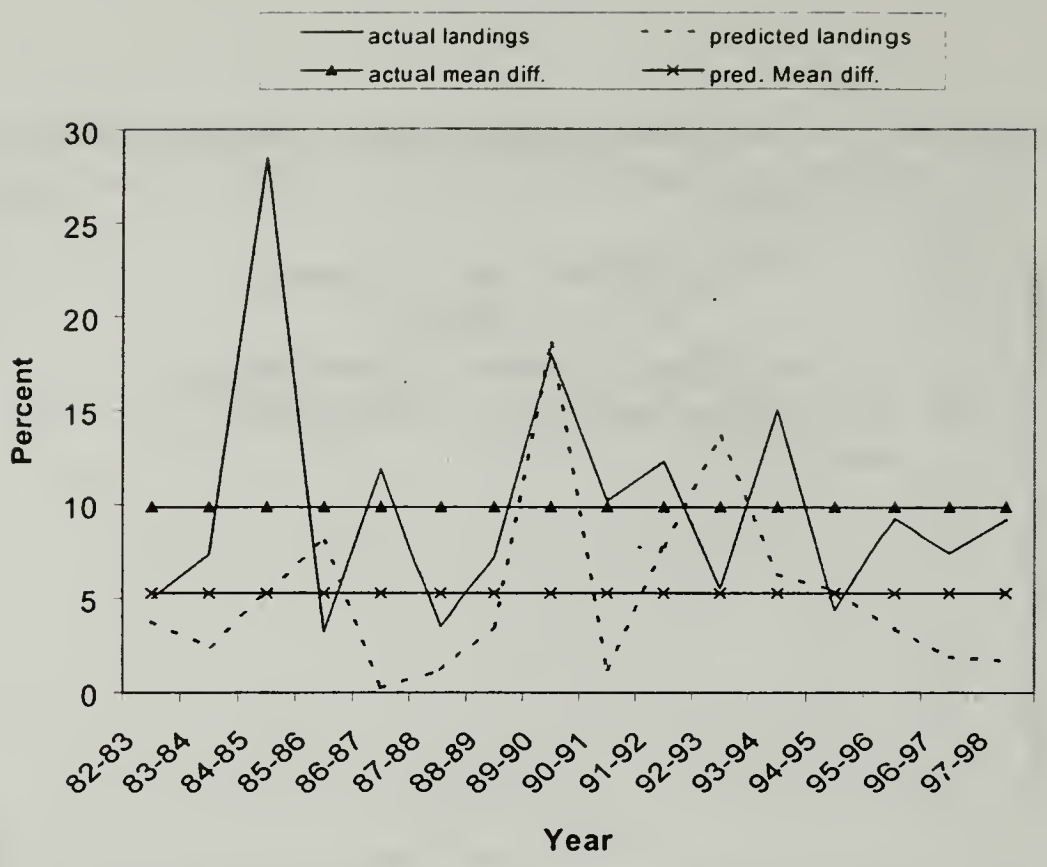

Figure 8. Absolute percent change in MA territorial landings and predicted landings.

Water Temperature Time Series

In 1985, a coastal bottom water temperature monitoring project was initiated. Temperature monitors (RYAN Tempmentor) have been deployed for various lengths of time at several sites in Cape Cod Bay, outside Boston Harbor, and Buzzards Bay (Figure 8). Some of these sites are located on ship wrecks.

The longest time series of bottom temperatures is from Cleveland Light in Buzzards Bay. The last monitor to be deployed was at Rocky Point, off Plymouth. The Rocky Point, Manomet Point, *Endicott*, and *Mars* sites represent the 0-30 ft., 30-60 ft., 61-90 ft., and 91-120 ft. depth strata, respectively, in Cape Cod Bay. The *Romance* (off Boston Harbor), and Buzzards Bay-South sites are located at 70-80 ft. and provide data from the north-south extremes in our series. The Cleveland Light monitor is located in 30 feet of water.

Monitors are retrieved and replaced annually by divers. Although the time series contained data from seven monitors at one point, we currently collect data from only six sites because the monitor at the *Endicott* site was lost and has not been replaced. Figures 9 and 10 present the bottom water temperature at sites in Buzzards Bay and Cape Cod Bay/Massachusetts Bay, respectively. Figure 11 provides a comparison between the annual mean bottom temperature at Cleveland Light, Manomet, *Mars*, and *Romance* and the annual mean surface temperature at Boston and Woods Hole provided by NOAA/NOS.

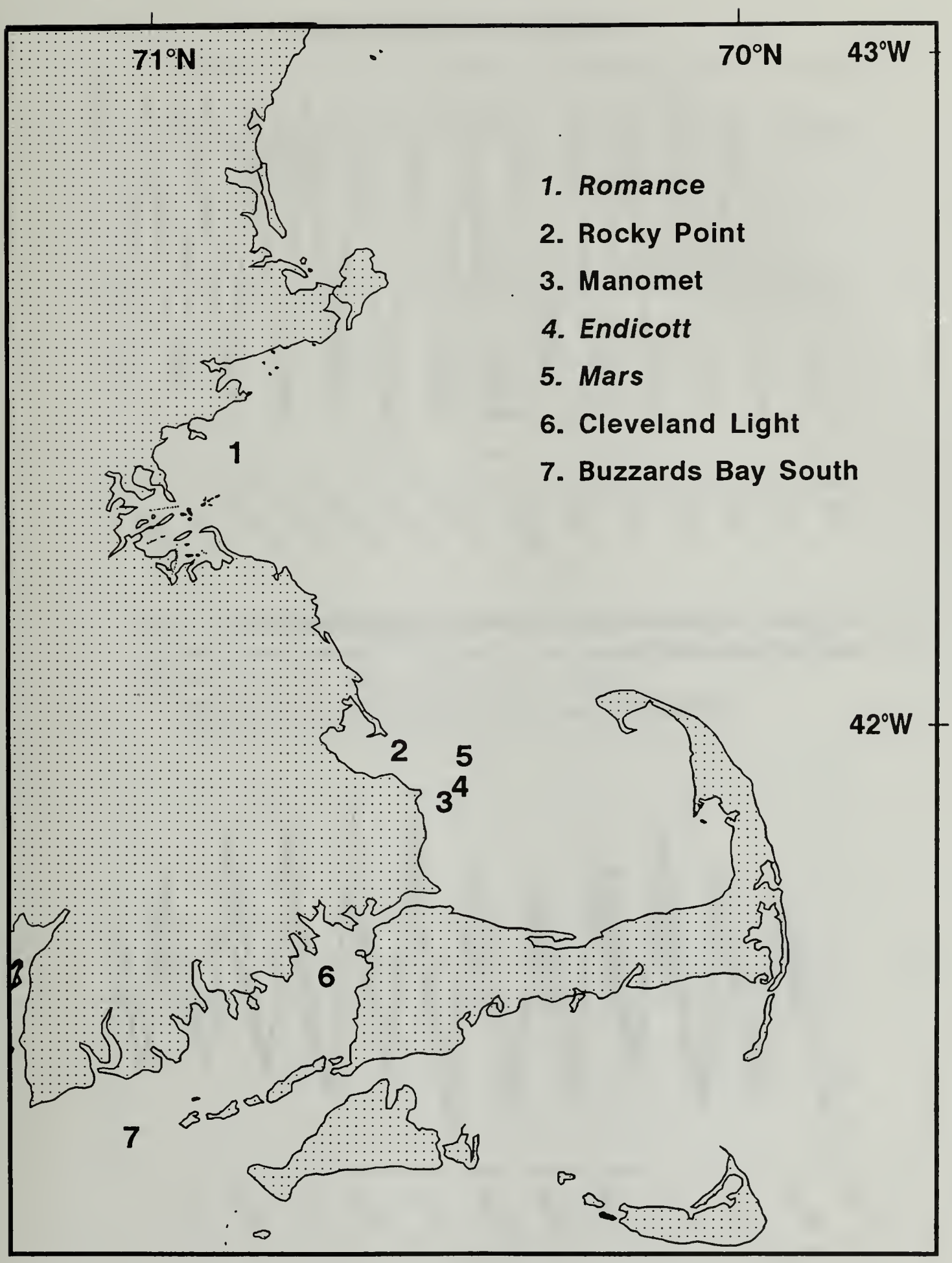

Figure 8. Map of Massachusetts with approximate locations of seven bottom temperature monitors indicated.

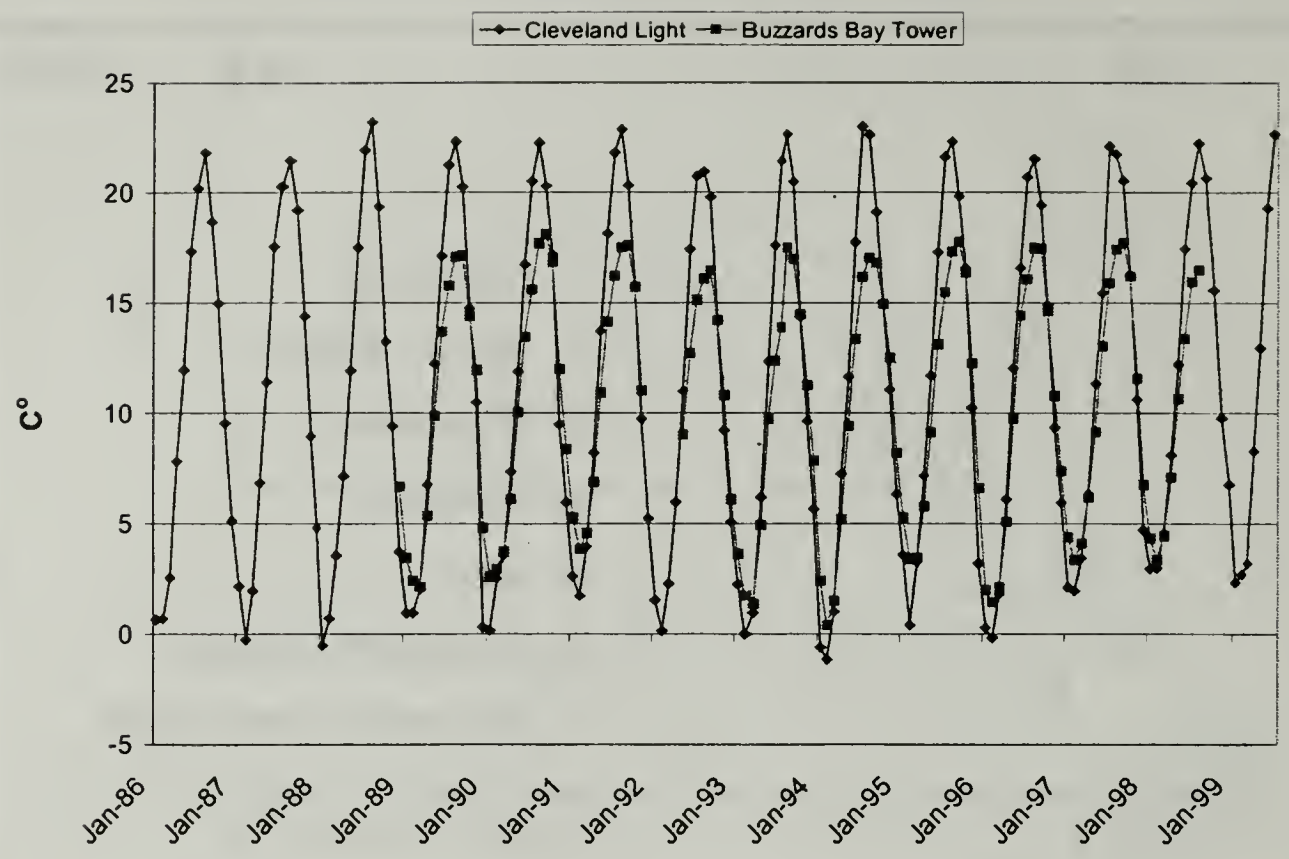

Figure 9. Mean monthly bottom water temperatures at two sites in Buzzards Bay.

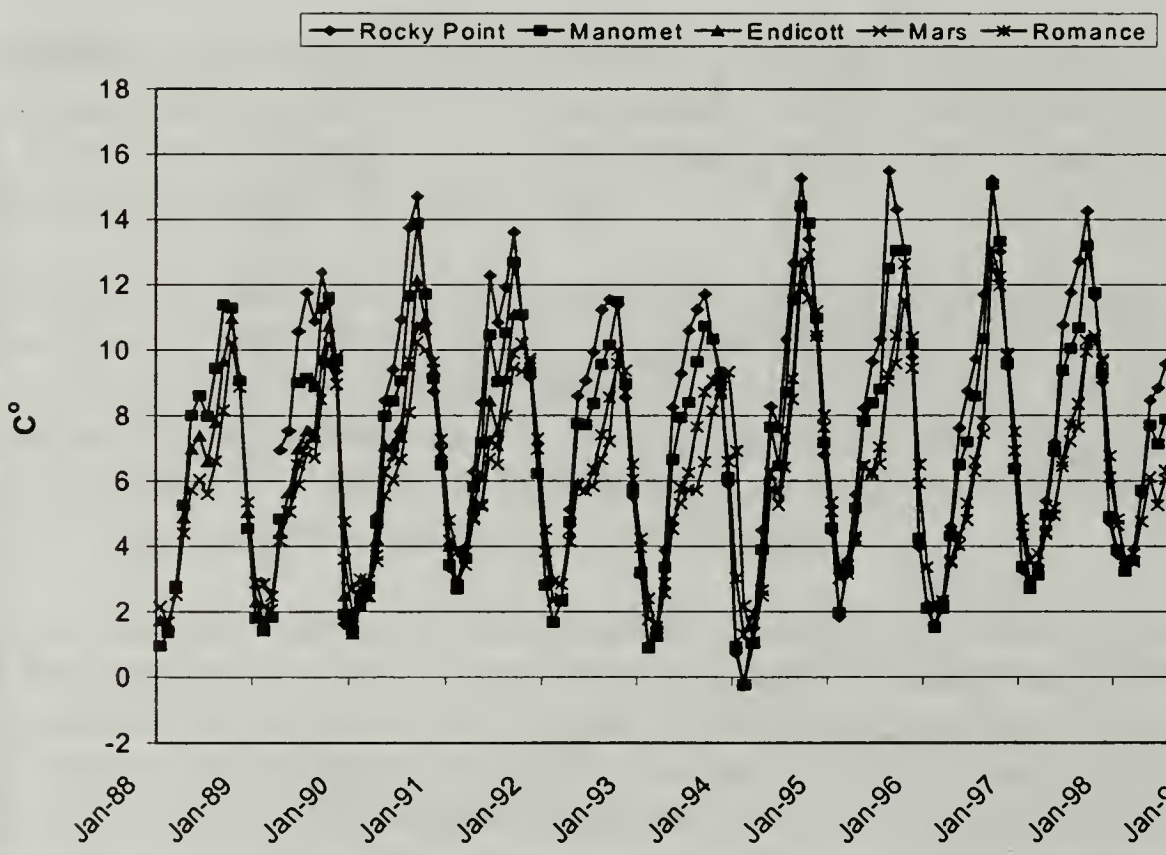

Figure 10. Mean monthly bottom water temperatures at five sites in the Gulf of Maine.

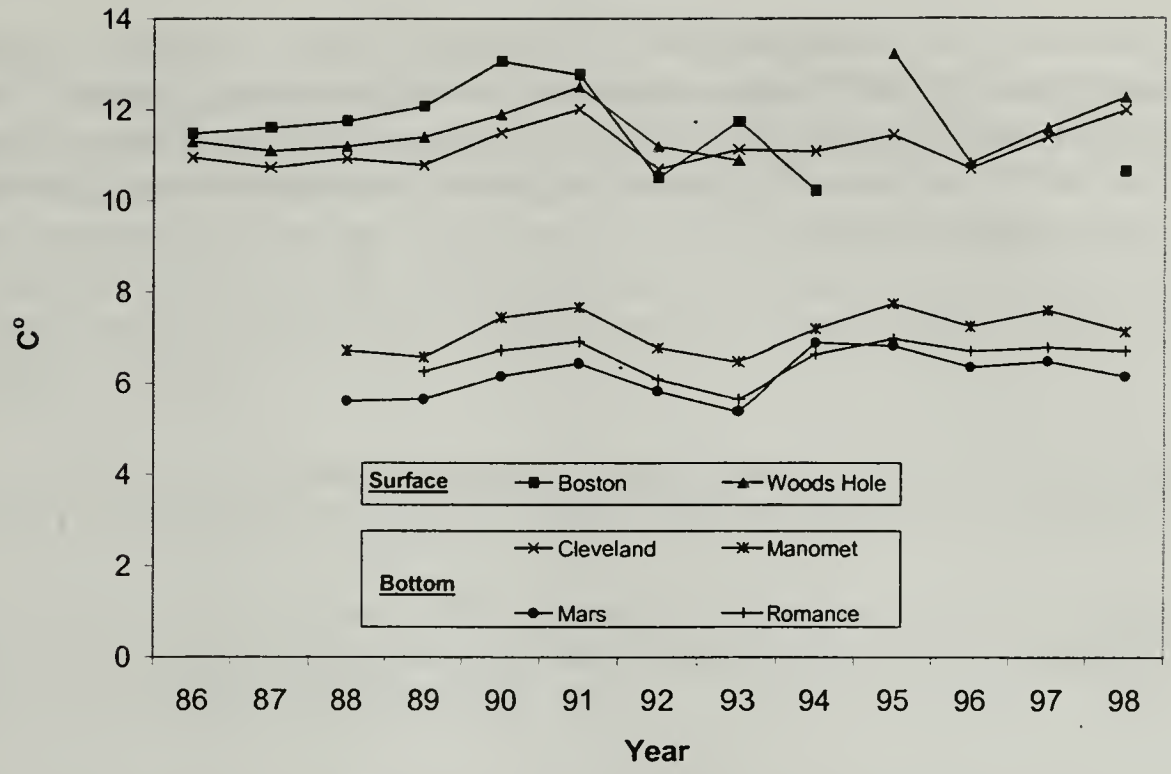

Figure 11. Mean annual bottom water temperatures at four sites monitored by the Coastal Lobster Project and mean annual surface temperature at two sites monitored by NOAA/NOS, 1986 - 1998.

ACKNOWLEDGEMENTS

We are indebted to the many commercial lobstermen whose cooperative spirit and concern for the American lobster resource sustain our lobster monitoring program. Gratitude is also extended to Bill Hoffman, Brad Chase, and Rob Johnston for data collection, Ann Spires, for data entry, and James Fair who administered the project and reviewed the manuscript. We also thank Thomas Hoopes for his data entry software design and assistance in data quality control.

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APPENDIX

Table 1. CTH'3, by state and region, for all marketable lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
Cape Ann	0.732	0.808	0.624	0.663	0.634	0.699	0.669	0.496	0.721	0.904	0.868	0.724	0.770	1.015	0.979	1.272	1.106	0.645
Beverly-Salem	0.934	0.898	0.881	0.835	0.663	0.496	0.611	0.661	0.639	0.827	0.586	0.390	0.509	0.898	0.840	0.788	0.419	0.767
Boston Harbor	---	---	---	1.108	1.254	1.096	1.058	1.057	1.123	1.224	1.160	0.734	0.750	0.725	0.626	0.534	0.638	0.462
Cape Cod Bay	0.710	0.776	0.680	0.479	0.716	0.822	0.533	0.752	0.539	0.630	0.693	0.567	0.494	1.052	0.906	0.662	0.760	0.633
Outer Cape Cod	0.808	0.824	0.765	0.598	0.856	0.811	0.937	0.861	0.923	1.219	1.148	1.339	1.021	1.105	1.117	1.027	0.837	0.785
Buzzards Bay	0.611	0.571	1.110	0.870	0.953	0.907	0.952	1.064	0.934	0.598	0.575	0.817	0.834	0.852	0.893	0.866	1.169	0.719

Table 2. CTHSOD, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
Cape Ann	0.067	0.109	0.586	0.450	0.395	0.474	0.417	0.388	0.670	0.589	0.728	0.726	0.447	0.658	0.800	0.573	0.831	0.356
Beverly-Salem	0.708	0.711	1.263	0.948	0.833	0.801	0.863	0.353	0.780	0.408	0.324	0.411	0.406	0.314	0.334	0.277	0.231	0.364
Boston Harbor	---	---	---	0.901	1.162	1.138	1.156	0.639	0.966	1.103	0.924	0.839	0.800	0.690	0.782	0.688	0.651	0.754
Cape Cod Bay	0.710	1.013	0.639	0.322	0.594	0.551	0.371	0.438	0.595	0.727	0.716	0.298	0.436	0.313	0.307	0.217	0.256	0.204
Outer Cape Cod	0.037	0.024	0.038	0.033	0.035	0.027	0.088	0.064	0.066	0.078	0.077	0.088	0.075	0.045	0.060	0.051	0.053	0.043
Buzzards Bay	0.787	0.620	0.638	0.785	0.848	1.312	0.871	1.153	1.188	1.236	1.072	0.784	1.156	0.649	0.492	0.540	0.510	0.254

Table 3. CTHAUL, by state and region, for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
Cape Ann	0.256	0.199	1.044	0.909	1.031	1.126	1.143	1.062	1.765	1.782	1.783	1.661	1.562	1.725	2.323	1.660	1.940	1.074
Beverly-Salem	1.855	1.713	2.526	2.504	2.567	2.435	3.482	1.862	3.477	1.867	1.563	1.502	1.540	1.717	1.920	1.654	1.988	2.038
Boston Harbor	---	---	---	2.773	3.038	3.314	3.334	1.959	3.104	3.382	2.451	2.069	2.284	2.189	2.390	2.511	2.258	2.864
Cape Cod Bay	1.544	1.680	1.345	0.825	1.337	1.512	1.031	1.442	1.742	1.921	2.086	1.065	1.334	1.033	1.102	0.873	0.926	0.701
Outer Cape Cod	0.233	0.145	0.210	0.189	0.160	0.161	0.324	0.353	0.306	0.453	0.452	0.490	0.474	0.288	0.359	0.372	0.354	0.301
Buzzards Bay	2.381	1.916	2.316	1.965	2.452	3.118	3.090	3.722	3.984	3.994	3.181	2.602	3.501	2.179	1.599	1.835	2.051	1.546

Table 4. Percent of females ovigerous, by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
Cape Ann	1.7	3.1	4.4	3.2	4.6	5.0	4.5	3.5	6.3	6.9	4.3	6.7	9.3	4.7	5.3	6.4	8.3	9.3
Beverly-Salem	1.7	2.8	1.2	0.4	1.9	1.1	1.8	1.5	1.6	1.8	3.2	3.9	5.4	2.3	6.3	6.9	8.3	6.1
Boston Harbor	---	---	---	1.4	1.2	2.0	1.7	2.0	2.1	2.7	2.8	3.0	4.4	4.7	5.0	6.7	6.7	8.0
Cape Cod Bay	3.9	3.1	3.7	3.1	3.2	2.1	3.9	2.9	3.0	3.3	5.4	6.8	6.8	7.4	10.2	13.6	11.9	13.1
Outer Cape Cod	11.1	23.0	30.3	26.8	22.3	28.9	16.9	21.4	27.4	24.5	18.3	27.7	26.8	27.3	34.4	34.6	32.9	30.3
Buzzards Bay	16.0	16.9	32.5	26.6	25.0	25.3	31.0	27.8	29.2	35.0	28.2	28.8	40.9	22.1	26.0	23.6	22.2	32.9

Table 5. CTHSOD, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
Cape Ann	0.002	0.011	0.024	0.015	0.016	0.017	0.016	0.010	0.037	0.035	0.024	0.050	0.038	0.024	0.030	0.031	0.056	0.037
Beverly-Salem	0.011	0.009	0.008	0.003	0.011	0.004	0.010	0.004	0.009	0.005	0.008	0.014	0.020	0.008	0.017	0.015	0.013	0.016
Boston Harbor	---	---	---	0.009	0.007	0.015	0.012	0.012	0.010	0.028	0.017	0.017	0.026	0.024	0.028	0.032	0.035	0.046
Cape Cod Bay	0.020	0.025	0.016	0.009	0.015	0.010	0.012	0.009	0.014	0.017	0.028	0.016	0.023	0.022	0.034	0.035	0.027	0.032
Outer Cape Cod	0.012	0.028	0.040	0.030	0.038	0.032	0.034	0.030	0.043	0.055	0.038	0.076	0.053	0.046	0.081	0.085	0.062	0.045
Buzzards Bay	0.079	0.053	0.230	0.183	0.193	0.297	0.234	0.289	0.270	0.349	0.073	0.197	0.446	0.110	0.088	0.098	0.083	0.067

Table 6. CTHAUL, by state and region, for all ovigerous female American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
Cape Ann	0.010	0.016	0.038	0.027	0.039	0.047	0.048	0.031	0.096	0.109	0.056	0.088	0.135	0.064	0.085	0.081	0.124	0.097
Beverly-Salem	0.025	0.033	0.016	0.006	0.033	0.018	0.036	0.021	0.039	0.023	0.049	0.047	0.067	0.048	0.106	0.103	0.136	0.101
Boston Harbor	---	---	---	0.030	0.025	0.050	0.037	0.038	0.043	0.075	0.064	0.046	0.081	0.088	0.100	0.124	0.132	0.181
Cape Cod Bay	0.048	0.048	0.040	0.024	0.040	0.031	0.038	0.034	0.039	0.055	0.091	0.056	0.078	0.075	0.128	0.147	0.130	0.110
Outer Cape Cod	0.081	0.178	0.242	0.170	0.176	0.225	0.157	0.198	0.258	0.342	0.251	0.453	0.317	0.306	0.514	0.561	0.408	0.307
Buzzards Bay	0.243	0.139	0.828	0.515	0.555	0.748	0.889	0.929	0.953	1.291	0.359	0.847	1.438	0.383	0.343	0.414	0.477	0.527

Table 7. Estimated fishing pressure index, by state and region, commercial lobster trap catch survey, Massachusetts coastal water, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
Cape Ann	91	92	87	89	87	87	88	90	84	81	90	87	83	86	88	85	88	85
Beverly-Salem	89	92	94	88	96	96	97	98	96	95	97	98	96	96	95	95	96	94
Boston Harbor	---	---	---	93	94	96	96	96	96	95	96	95	96	95	94	95	94	96
Cape Cod Bay	90	93	92	94	93	94	92	94	94	93	91	92	94	90	86	88	87	90
Outer Cape Cod	46	43	42	38	48	46	54	57	47	50	54	57	60	60	55	54	57	58
Buzzards Bay	98	96	96	94	96	97	97	97	95	94	95	97	97	98	96	95	92	96

Table 8A. Total instantaneous (Z)* and total annual (A)** mortality estimates (Gulland, 1969) of American lobster by state and region, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
	[illegible]																	
Cape Ann	1.65	2.18	1.72	1.92	1.94	2.03	1.85	1.75	1.55	1.39	1.97	1.87	1.51	1.81	1.95	1.90	2.00	1.65
	81%	89%	82%	85%	86%	87%	84%	83%	79%	75%	86%	85%	78%	84%	86%	85%	86%	81%
Beverly-Salem	1.97	2.15	2.41	2.71	3.64	3.60	3.49	3.31	3.59	2.81	3.49	3.12	2.62	3.34	3.10	2.90	2.46	2.81
	86%	88%	91%	93%	97%	97%	97%	96%	97%	94%	97%	96%	93%	96%	95%	94%	91%	94%
Boston Harbor	---	---	---	2.52	3.59	2.60	2.77	2.86	2.96	3.00	3.40	3.54	3.26	3.21	2.87	2.65	2.77	2.59
	---	---	---	92%	97%	93%	94%	94%	95%	95%	97%	97%	96%	96%	94%	93%	94%	92%
Cape Cod Bay	2.53	2.69	2.42	2.52	2.31	2.83	2.26	2.74	2.43	2.46	2.33	2.58	2.60	3.10	2.35	2.09	2.14	2.02
	92%	93%	91%	92%	90%	94%	90%	94%	91%	91%	90%	92%	93%	95%	90%	88%	88%	87%
Outer Cape Cod	0.43	0.46	0.42	0.33	0.52	0.51	0.80	0.71	0.62	0.63	0.77	0.78	0.87	0.92	0.74	0.73	0.89	0.86
	35%	37%	34%	28%	41%	40%	55%	51%	46%	47%	54%	54%	58%	60%	52%	52%	59%	58%
Buzzards Bay	3.02	3.00	8.64	3.14	3.55	3.71	3.48	3.18	3.13	2.60	3.50	3.81	3.03	3.58	3.34	2.84	2.74	3.27
	95%	95%	99%	96%	97%	98%	97%	96%	96%	93%	97%	98%	95%	97%	96%	94%	94%	96%

Table 8B. Total instantaneous (Z)* and total annual (A)** mortality estimates (Beverton and Holt, 1956) of American lobster by state and region, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
	[illegible]																	
Cape Ann	1.32	1.39	1.35	1.52	1.33	1.32	1.39	1.51	1.27	1.66	1.77	1.57	1.38	1.48	1.62	1.49	1.67	1.52
	73%	75%	74%	78%	74%	73%	75%	78%	72%	81%	83%	79%	75%	77%	80%	77%	81%	78%
Beverly-Salem	1.59	1.70	1.85	1.78	1.96	1.99	2.16	1.98	2.01	1.83	2.29	2.50	2.23	2.18	2.09	2.11	2.28	2.18
	80%	82%	84%	83%	86%	86%	88%	86%	87%	84%	90%	92%	89%	89%	88%	88%	90%	89%
Boston Harbor	---	---	---	1.82	1.75	1.92	1.88	1.84	1.94	1.87	2.19	2.14	2.33	2.28	2.09	2.18	2.09	2.63
	---	---	---	84%	83%	85%	85%	84%	86%	85%	89%	88%	90%	90%	88%	89%	88%	93%
Cape Cod Bay	1.64	1.92	1.72	2.07	1.88	1.92	1.78	1.87	1.97	1.95	1.96	2.01	2.14	1.93	1.65	1.66	1.57	1.65
	81%	85%	82%	87%	85%	85%	83%	85%	86%	86%	86%	87%	88%	86%	81%	81%	79%	81%
Outer Cape Cod	0.54	0.55	0.53	0.52	0.57	0.55	0.66	0.66	0.62	0.63	0.71	0.72	0.78	0.79	0.72	0.68	0.76	0.76
	42%	42%	41%	41%	43%	42%	48%	48%	46%	47%	51%	51%	54%	55%	51%	49%	53%	53%
Buzzards Bay	2.97	2.53	2.26	2.21	2.36	2.41	2.36	2.35	2.14	2.27	3.08	2.70	3.11	2.85	2.44	2.37	2.14	2.57
	95%	92%	90%	89%	91%	91%	91%	94%	88%	90%	95%	93%	96%	94%	91%	91%	88%	92%

Table 9. Instantaneous fishing mortality estimates (F), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
Cape Ann	1.33	1.47	1.11	1.33	1.28	1.22	1.30	1.37	1.12	1.04	1.50	1.32	1.14	1.25	1.36	1.28	1.41	1.26
Beverly-Salem	1.42	1.47	1.64	1.68	1.81	1.93	1.89	2.02	1.95	1.86	2.08	2.16	1.96	1.94	1.88	1.91	2.01	1.87
Boston Harbor	---	---	---	1.77	1.70	1.80	1.87	1.83	1.94	1.86	2.01	1.97	1.97	1.90	1.85	1.89	1.79	2.13
Cape Cod Bay	1.53	1.60	1.58	1.73	1.59	1.70	1.56	1.70	1.82	1.72	1.66	1.71	1.85	1.66	1.47	1.44	1.47	1.52
Outer Cape Cod	0.47	0.48	0.45	0.42	0.47	0.47	0.57	0.53	0.54	0.51	0.59	0.61	0.65	0.68	0.62	0.59	0.65	0.64
Buzzards Bay	2.32	2.13	1.94	1.80	2.04	2.11	2.08	2.06	1.95	1.97	2.34	2.26	2.39	2.31	2.05	1.98	1.75	2.06

Table 10. Estimated exploitation rate (u), by state and region, commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
Cape Ann	0.74	0.80	0.61	0.68	0.71	0.67	0.70	0.71	0.63	0.51	0.70	0.67	0.62	0.65	0.67	0.66	0.68	0.65
Beverly-Salem	0.71	0.71	0.75	0.79	0.79	0.83	0.77	0.88	0.76	0.85	0.82	0.79	0.78	0.79	0.79	0.80	0.79	0.76
Boston Harbor	---	---	---	0.82	0.81	0.80	0.84	0.84	0.86	0.85	0.82	0.81	0.76	0.75	0.78	0.77	0.75	0.75
Cape Cod Bay	0.75	0.71	0.75	0.73	0.72	0.75	0.73	0.77	0.79	0.76	0.73	0.74	0.76	0.74	0.72	0.70	0.74	0.75
Outer Cape Cod	0.37	0.37	0.35	0.33	0.36	0.36	0.41	0.38	0.40	0.38	0.42	0.44	0.45	0.47	0.44	0.43	0.45	0.45
Buzzards Bay	0.74	0.78	0.77	0.72	0.79	0.80	0.80	0.82	0.80	0.78	0.72	0.78	0.74	0.76	0.76	0.76	0.72	0.74

Table 11. Mean carapace length (mm), by state and region, for all marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
State	[illegible]																	
Cape Ann	88.6	88.3	88.3	87.9	88.4	88.3	88.0	88.3	89.3	90.3	88.4	88.8	89.6	89.6	88.7	89.5	88.7	89.0
Beverly-Salem	87.6	87.0	86.6	86.9	86.2	86.2	85.8	87.1	87.7	88.3	87.5	87.2	87.5	87.8	88.0	87.9	87.5	87.7
Boston Harbor	---	---	---	86.8	86.9	86.4	86.6	87.5	88.0	88.1	87.8	87.9	87.5	87.5	88.0	87.7	87.8	87.0
Cape Cod Bay	87.2	86.4	86.9	86.1	86.4	86.3	86.7	87.3	87.7	87.7	88.1	88.2	87.7	88.3	89.2	89.0	89.4	89.0
Outer Cape Cod	98.2	97.5	97.4	99.7	97.0	96.3	94.6	95.2	96.5	96.1	95.3	95.2	93.8	94.2	94.2	94.9	93.9	94.1
Buzzards Bay	84.7	85.2	85.7	85.8	85.2	85.3	85.3	86.1	87.4	87.0	86.4	86.9	86.5	86.5	87.4	87.3	87.8	87.0

Table 12. Mean carapace length (mm), by state and region for all sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters,

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Cape Ann	78.0	77.7	77.5	77.3	77.6	77.1	75.9	77.0	78.3	78.8	78.7	77.9	78.3	78.0	77.2	77.3	77.3	77.8
Beverly-Salem	74.3	76.5	74.9	76.1	75.9	74.7	74.7	74.5	76.4	76.1	73.4	73.5	75.1	75.8	76.2	76.8	76.0	74.9
Boston Harbor	---	---	---	77.1	76.9	76.9	76.5	75.6	76.8	77.4	75.4	74.6	75.3	76.0	77.3	76.9	76.3	72.7
Cape Cod Bay	76.6	76.4	76.7	75.6	76.1	76.2	75.6	76.9	77.9	77.8	77.4	76.8	76.7	78.6	78.6	79.8	79.1	79.3
Outer Cape Cod	75.9	76.2	77.1	75.1	76.6	75.9	77.0	77.1	76.8	78.8	78.8	79.0	79.4	78.3	80.0	79.9	80.0	79.6
Buzzards Bay	75.8	75.5	76.8	76.4	76.1	76.0	76.6	76.3	77.7	77.4	76.6	77.1	78.3	77.6	77.7	77.5	78.2	78.9

Table 13. Mean carapace length (mm) of all ovigerous female American lobster, by state and region, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Cape Ann	109.0	100.3	94.3	90.5	93.8	95.0	91.6	94.0	100.4	95.1	91.7	91.9	91.0	92.7	93.3	91.5	90.7	91.3
Beverly-Salem	80.5	84.5	85.8	83.5	85.9	83.5	81.8	83.0	85.2	85.5	83.8	81.6	82.6	83.1	83.3	83.0	82.5	83.0
Boston Harbor	---	---	---	82.1	84.0	81.3	82.3	83.7	83.0	83.8	82.0	82.0	80.8	80.9	81.5	82.4	82.2	79.8
Cape Cod Bay	86.4	83.8	85.5	84.4	85.2	86.8	87.0	84.7	86.1	85.0	83.9	84.1	83.0	84.8	85.2	85.7	85.8	86.1
Outer Cape Cod	109.8	106.1	108.0	107.1	106.9	107.3	102.5	105.2	105.4	104.6	101.9	99.2	100.7	100.0	100.6	99.6	98.9	98.3
Buzzards Bay	78.1	79.6	81.6	83.0	80.1	79.4	80.2	80.6	81.3	80.8	79.8	79.9	81.0	81.5	81.8	82.6	84.0	82.7

Table 14. Cull rate (percent), by state and region, for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal water, 1981-1998.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Cape Ann	10.0	9.8	10.5	11.5	23.9	25.3	20.2	21.2	16.7	16.7	19.7	18.2	19.2	17.1	19.6	18.0	18.9	17.6
Beverly-Salem	8.3	8.6	10.2	20.9	23.0	30.0	24.1	26.3	28.6	27.3	28.9	22.7	28.3	30.8	25.1	24.6	23.4	25.1
Boston Harbor	---	---	---	13.3	19.3	19.1	16.9	16.3	13.8	14.7	13.5	17.2	23.4	23.0	22.2	17.8	19.8	17.4
Cape Cod Bay	11.1	10.7	10.9	15.6	18.3	21.6	16.2	17.4	22.8	20.5	18.9	18.3	18.1	19.4	21.5	16.2	23.6	25.6
Outer Cape Cod	5.7	11.3	8.9	13.0	13.4	16.1	12.6	15.0	14.0	15.5	13.2	15.7	17.3	20.1	19.0	13.3	14.5	14.2
Buzzards Bay	13.5	14.7	12.4	12.4	13.4	14.6	15.1	15.6	12.6	13.6	13.9	19.3	20.5	24.0	24.4	15.0	15.6	16.2

Table 15. Cull rate (percent), by state and region, for all legal-sized American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Cape Ann	10.7	9.6	7.5	10.4	19.4	20.3	18.0	19.3	13.9	13.7	16.8	18.3	16.3	16.5	16.2	14.7	15.7	16.3
Beverly-Salem	4.3	7.7	7.4	15.5	19.3	22.1	17.1	21.4	18.7	25.6	22.8	19.9	24.6	25.4	18.8	20.2	17.2	20.0
Boston Harbor	---	---	---	10.1	16.2	15.8	12.9	13.1	9.9	9.9	12.3	14.0	17.5	18.0	20.1	17.3	17.3	14.2
Cape Cod Bay	9.3	9.3	10.0	13.2	14.5	18.1	15.0	15.6	12.0	16.3	17.8	16.8	16.3	21.7	23.3	16.0	25.3	26.2
Outer Cape Cod	5.3	10.3	8.1	13.3	12.5	14.9	13.1	14.3	13.3	14.1	12.8	15.3	16.4	19.9	18.3	12.6	13.6	13.5
Buzzards Bay	16.1	13.2	12.7	12.3	13.8	13.6	15.2	14.1	12.6	12.6	11.5	22.2	18.9	23.5	22.6	12.9	15.3	14.4

Table 16. Cull rate (percent), by state and region, for marketable American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Cape Ann	10.8	9.8	7.3	10.5	20.9	20.7	18.4	19.9	14.0	14.2	16.8	18.1	13.7	16.7	16.0	14.5	15.3	16.3
Beverly-Salem	4.4	8.0	7.4	15.6	18.5	22.2	17.2	21.3	18.9	23.8	23.1	20.0	24.7	25.5	19.0	20.0	17.0	20.1
Boston Harbor	---	---	---	10.2	16.2	15.7	12.8	13.1	9.9	9.9	12.4	14.0	17.5	18.0	20.1	17.4	17.4	14.5
Cape Cod Bay	9.3	9.3	10.0	13.2	15.9	18.2	14.8	15.6	19.1	16.2	17.8	16.7	16.2	22.3	23.3	16.6	25.5	26.1
Outer Cape Cod	5.3	10.9	8.6	14.8	12.9	16.8	13.2	14.9	13.9	14.6	14.1	16.8	17.3	21.6	20.4	14.0	13.7	14.0
Buzzards Bay	16.9	13.1	12.3	12.6	15.4	14.1	15.4	14.7	13.0	12.4	11.7	22.5	19.4	23.7	23.0	13.1	14.5	15.1

Table 17. Cull rate (percent), by state and region, for sub-legal American lobster, sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Cape Ann	8.0	10.6	12.6	12.2	26.9	28.7	21.5	22.1	17.9	18.3	21.0	18.2	20.9	17.4	21.2	20.6	20.8	18.4
Beverly-Salem	10.0	9.0	11.2	22.3	24.0	31.8	25.3	28.6	30.8	29.2	31.6	23.5	29.5	33.8	28.2	26.7	25.5	27.2
Boston Harbor	---	---	---	14.5	20.5	20.0	18.0	18.0	15.2	16.4	13.9	18.3	25.3	24.7	22.8	17.9	20.6	18.0
Cape Cod Bay	11.9	11.3	11.4	17.0	20.2	23.4	16.8	18.3	24.0	21.8	19.2	19.0	18.8	17.8	20.1	16.3	22.2	25.2
Outer Cape Cod	7.8	17.9	13.5	11.7	18.6	22.8	11.0	16.9	17.1	20.7	14.3	17.1	20.2	21.3	21.8	15.7	17.9	16.6
Buzzards Bay	12.7	15.2	12.2	12.4	13.3	14.9	15.0	16.2	12.6	13.9	14.5	18.3	21.0	24.2	25.6	16.4	15.8	17.4

Table 18. Percent trap mortality by state and region for all American lobster sampled during commercial lobster trap catch survey, Massachusetts coastal waters, 1981-1998.

State	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Cape Ann	0.00	0.00	0.09	0.27	0.03	0.16	0.00	0.03	0.13	0.09	0.48	0.10	0.11	0.14	0.28	0.17	0.04	0.13
Beverly-Salem	0.00	0.00	0.00	0.00	0.04	0.22	0.03	0.19	0.14	0.29	0.41	0.13	0.19	0.13	0.74	0.49	0.37	0.31
Boston Harbor	---	---	---	0.00	0.03	0.03	0.23	0.09	0.03	0.04	0.01	0.03	0.06	0.04	0.01	0.04	0.08	0.08
Cape Cod Bay	0.00	0.02	0.03	0.00	0.00	0.02	0.15	0.00	0.02	0.05	0.02	0.02	0.02	0.00	0.03	0.03	0.03	0.08
Outer Cape Cod	0.46	0.22	0.23	0.48	0.40	0.85	0.27	0.66	0.47	0.62	0.35	0.24	0.30	0.58	0.38	0.43	0.21	0.25
Buzzards Bay	0.62	0.00	1.13	0.43	0.76	0.25	0.01	0.18	0.11	0.18	1.74	0.10	0.29	0.71	0.16	0.21	0.00	0.19